

SECTION II.—GENERAL METEOROLOGY.

DISTRIBUTION OF PRECIPITATION IN CHINA DURING THE
TYPHOONS OF THE SUMMER OF 1911.

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[Dated: Cambridge, Mass., June 22, 1916.]

In connection with a study of rainfall distribution in China, the writer studied the typhoons of the summer of 1911, using the data published in the latest report of the Zi-ka-wei Observatory. Of the 17 typhoons that occurred during that summer from June to September, inclusive, only 7 crossed the coast of China. Four of these seven will be discussed here. Their trajectories are sufficiently different from one another to indicate that they belong to different classes or types, but at present no attempt will be made to classify them. When drawing the maps of the accompanying precipitation, it is difficult to determine to which storm the precipitation belongs when two storms succeed each other closely. Owing to the scarcity of rainfall data for China, it is out of the question to undertake so thorough a discussion as Mr. Torahiko Terada¹ has given in his articles "The distribution of cyclonic precipitation in Japan." The individual rainfalls for each storm are given in Tables 1 and 2.

The following four rainfall-distribution maps of China are based upon the data contained in "Bulletin des Observations, 1911," of the Zi-ka-wei Observatory (Zi-ka-wei, 1915). On the fourth map (fig. 7) the rainfall data for the Japanese and the Philippine Islands are from other sources.² The storms are considered in the order of their complexity, the simplest first, and not in their chronological order of occurrence.

Typhoon of August 8-15, 1911. (No. 66.)

This storm (storm No. 66)³ caused heavy precipitation in Manchuria and central China, resulting in disastrous floods in the latter region. Several particulars should be mentioned in connection with this storm. The area of precipitation is quite symmetrical with respect to the storm track, and the intensity of rain decreases from the low center. The two areas of heavy rainfall, 100 mm. (3.9 in.) or more, are both situated at the places where the storm passed from ocean to land, one at the mouth of the Yangtze and the other near Newchwang. In Newchwang, where the average annual fall (for the period 1901-1911) amounts to only 638.2 mm. (25.1 in.), there was on August 13 a precipitation of 201 mm. (7.9 in.), or more than 30 per cent of the average yearly total.

Southern China did not receive any rainfall, probably owing to the fact that the trajectory of the storm was well to the north. The storm traveled a little slower on the continent than on the ocean.

The typhoon of September 24-October 11, 1911. (No. 76.)

In contrast with the preceding storm, this storm affected southern China but not northern China or Manchuria. The storm divided north of Luzon, one portion

going to Formosa and the other to Kwangtung (fig. 4.) So far as rainfall is concerned the latter branch is practically of no importance. The movement of the first branch was greatly retarded on entering Formosa. Between August 3 and 6 the storm center could not be located; its progress as shown on the map was very slow on these three days.

The rainfall distribution is uniform, as in the preceding storm, the heaviest precipitation occurring near the center of the storm. All of the rain fell in the period October 1-4, and most of it between the 1st to 3d, preceding the apparent stoppage of the storm center. There was no precipitation in northern China and practically no rain west of the line drawn between Hankow and Pakhoi.

The typhoon of June 28-July 8, 1911. (No. 55.)

This is chronologically the first typhoon of the year 1911 that is of any importance. The long trajectory of the storm (fig. 6) on the continent made the rainfall area more extensive than in the two preceding storms (fig. 5). Although the storm went far inland, the heavy precipitation occurred on the coast and at a distance from the center, except on the southern coast where the storm passed from sea to land. The distribution of rainfall is irregular and patchy. On the whole, however, the isohyets can be said to run parallel to the path of the storm. The velocity of the storm did not perceptibly diminish on land compared with its velocity at sea.

The typhoon of July 12-21, 1911. (No. 59.)

This storm is remarkable for its heavy rainfall in northern and central Luzon, P. I. (See fig. 7.) The precipitation at Baguio for the period July 14-17, 1911, amounted to 2,238.7 mm. (88.14 inches).⁴ From noon of July 14 to noon of the 15th the amount of precipitation, according to the Friez quadruple register at that station, was 1,168 mm. (45.98 inches), the heaviest 24-hour rainfall yet on record in any part of the world.⁵

The precipitation in Formosa and China did not approach that of Luzon in intensity, but it covered a considerable area on the continent. The area of heaviest precipitation in Formosa occurred at the extreme south, where the storm center passed. Rainfalls of more than 400 mm. (16 inches) were recorded at Hunchen and Taitung. In China also the heaviest precipitation occurred on the coast where the Low passed from sea to land (fig. 8). The two areas of heavy rainfall are located, one on the central Chinese coast and the other in southern Manchuria, almost on the same region where the heavy precipitation occurred in storm No. 66. The rainfall distribution on the continent is uniform, on the whole the trend of isohyets following the storm path. The southern coast of China had no precipitation throughout the period.

In Japan the uniformity of rainfall distribution is striking. There was no precipitation in Kiushu, Shukoku, southern part of Honshu, or the northern part of Yezo. The rainfall area had the shape of a semicircle, with the heaviest rainfall at the center, near Akita.

¹ See author's abstract in MONTHLY WEATHER REVIEW, March, 1916, 44: 127-128.² Data for stations in Japan, Korea, and Formosa are from Jour. Metl. soc., Japan, September, 1911, pp. 21-24.³ Data for stations in the Philippines are from Bull. Manila Central Observatory, Philippine Weather Bureau, July, 1911, pl. 4.⁴ The storm numbers are the original reference numbers assigned them in the Zi-ka-wei report. They are here retained for the convenience of future reference.⁵ Bulletin, Manila central observatory, July, 1911, pl. 4.⁶ McAdie, A. G. Rainfall of California. Berkeley, Cal., 1914. (Univ. Cal., Public. in geogr., v. 1, no. 4.) p. 171.

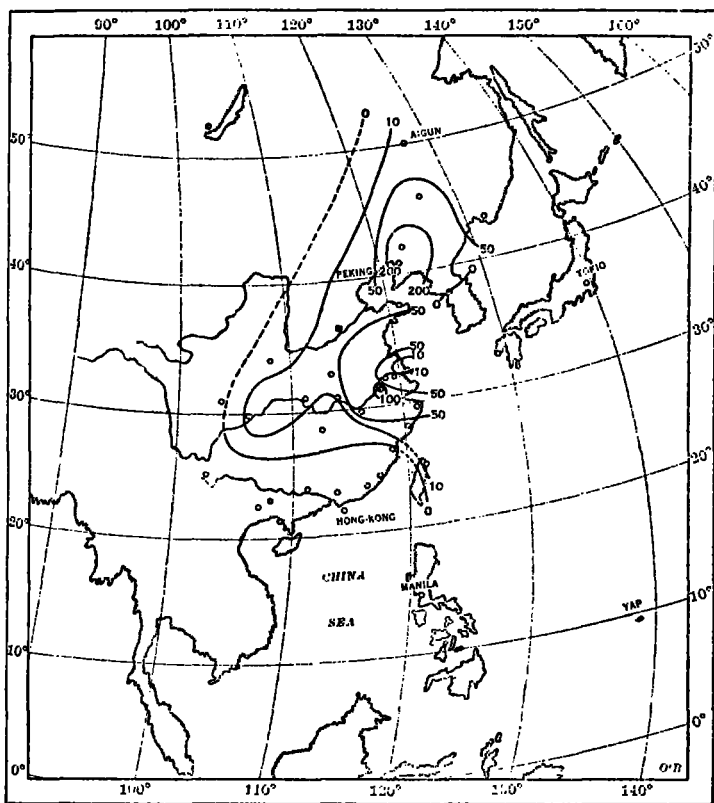


FIG. 1.—Distribution of precipitation accompanying the typhoon of August 8-15, 1911. (Storm No. 66.)

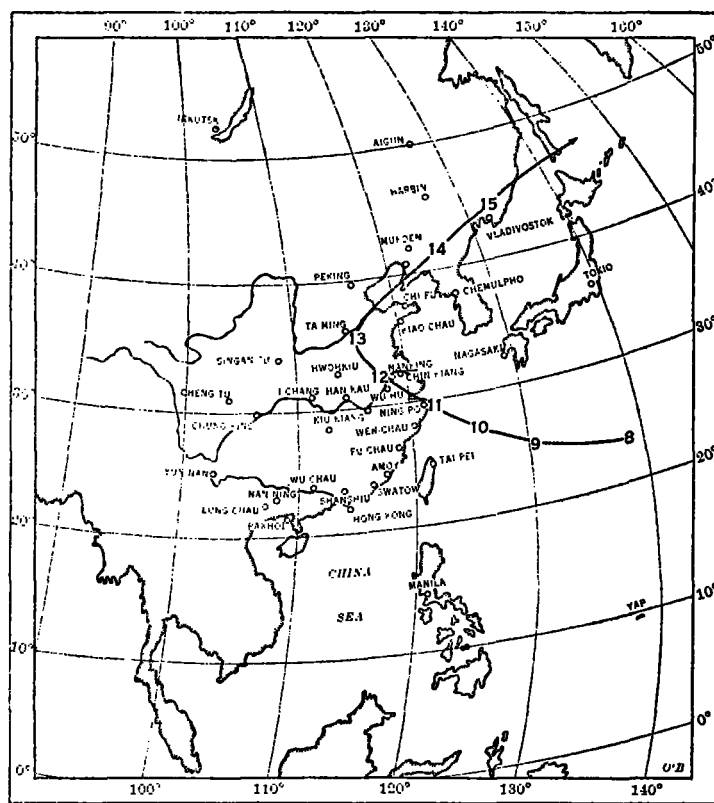


FIG. 2.—Track of the typhoon of August 8-15, 1911. (No. 66.)

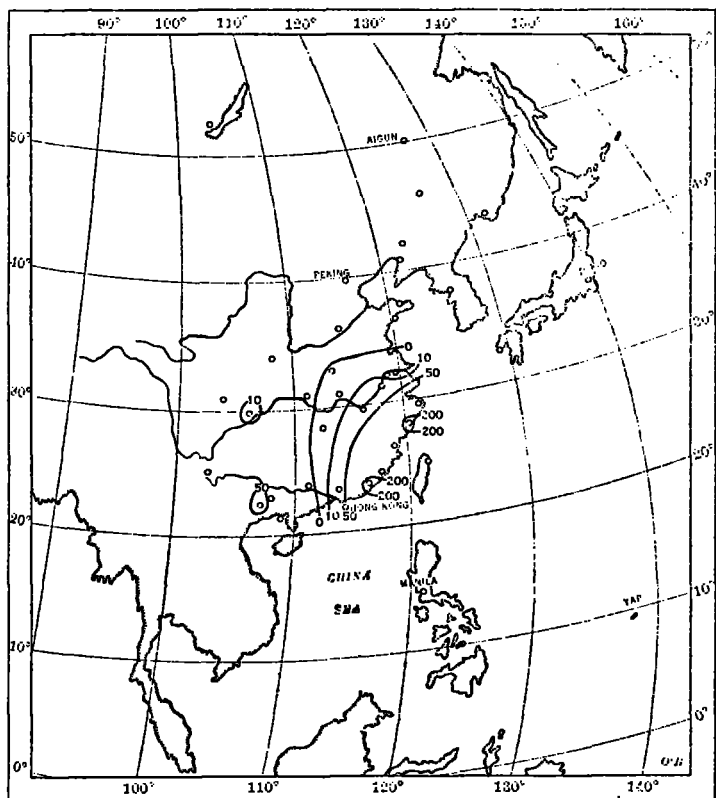


FIG. 3.—Distribution of precipitation accompanying the typhoon of September 24-October 11, 1911. (Storm No. 76.)

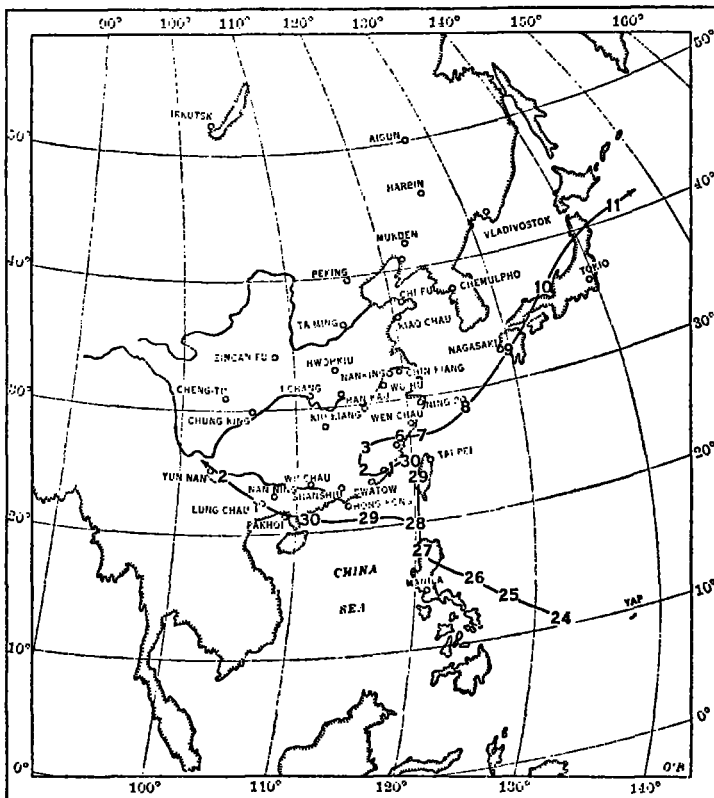


FIG. 4.—Track of the typhoon of September 24-October 11, 1911. (No. 76.)

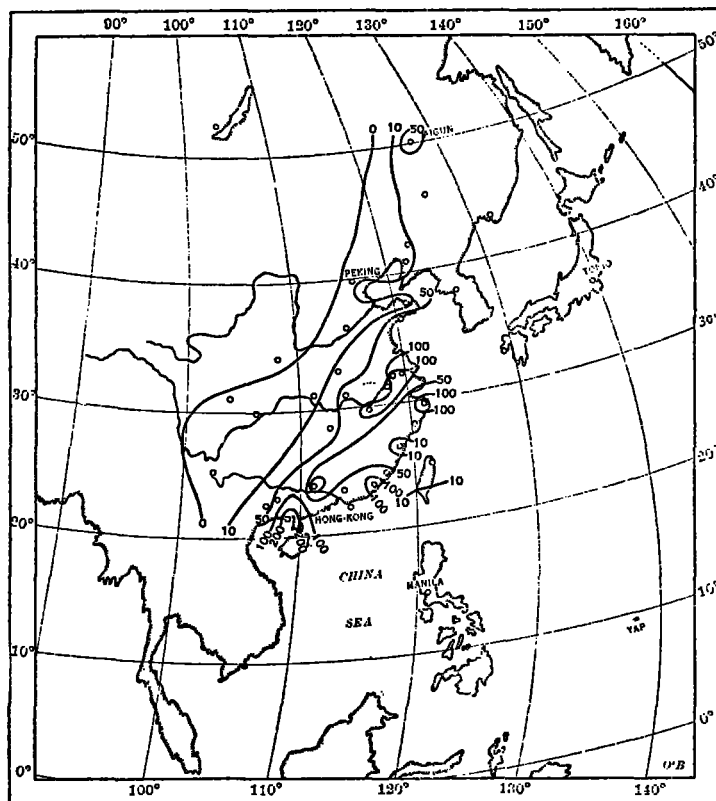


FIG. 5.—Distribution of precipitation accompanying the typhoon of June 28-July 8, 1911. (Storm No. 55.)

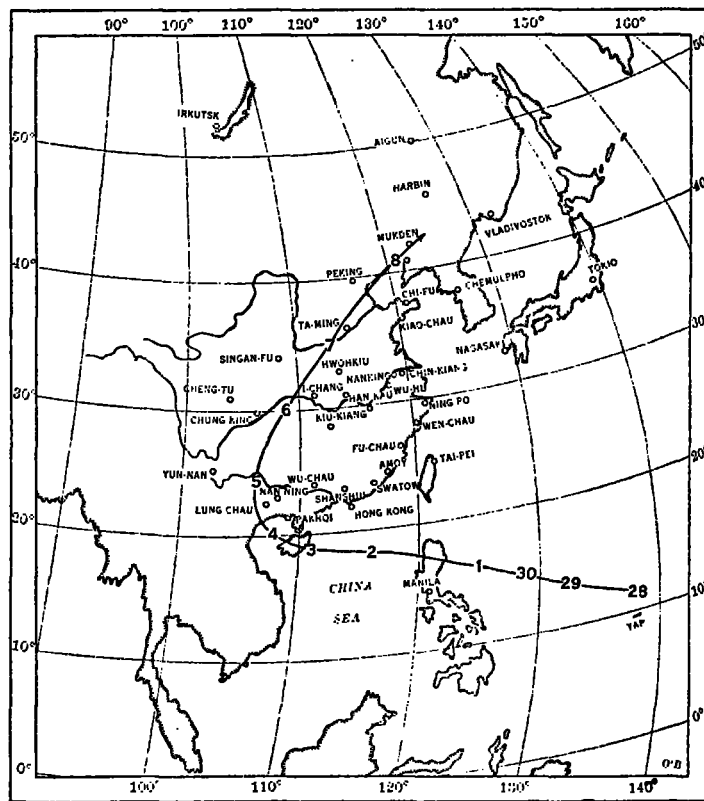


FIG. 6.—Track of the typhoon of June 28-July 8, 1911. (No. 55.)

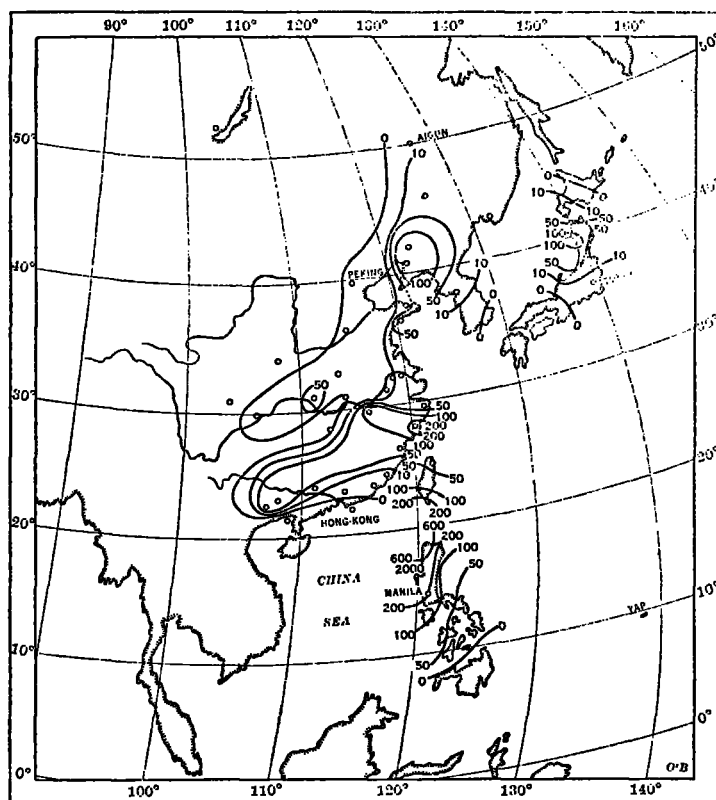


FIG. 7.—Distribution of precipitation accompanying the typhoon of July 12-21, 1911. (Storm No. 59.)

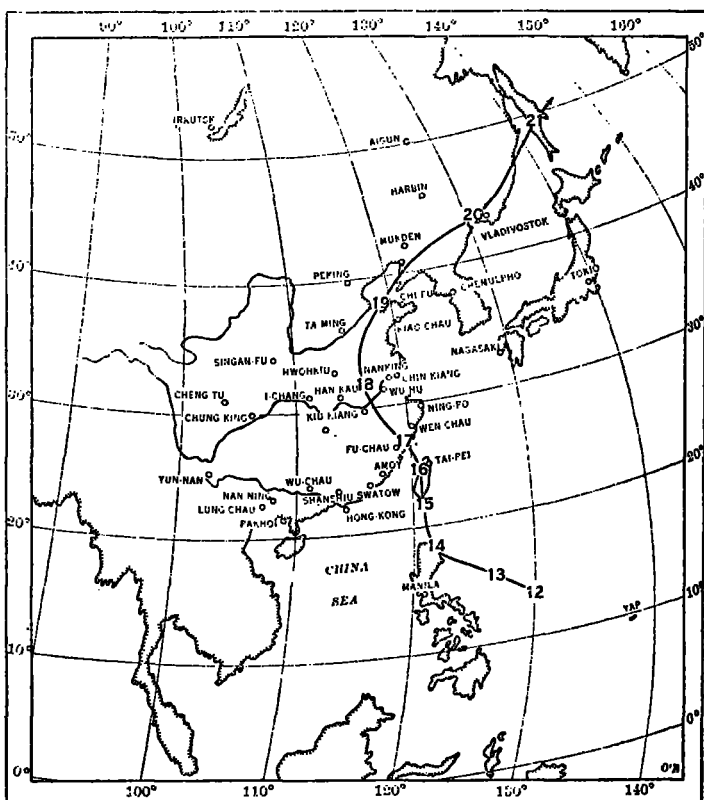


FIG. 8.—Track of the typhoon of July 12-21, 1911. (No. 59.)

It took the storm about five days to travel from Luzon to Manchuria and northern and central Japan. Rain occurred on the following days in the districts named: Luzon, 14th-17th; Formosa, 15th-19th; southern China, 15th-20th; central China, 17th-20th; northern China, Manchuria, and Korea, 18th-20th; in northern and central Japan on the 19th-22d.

TABLE 1.—*Rainfalls accompanying four typhoons of 1911.*

Stations.	June 28- July 8. No. 55.	July 12-21. No. 59.	Aug. 8- 15. No. 66.	Sept. 24- Oct. 11. No. 76.
CHINA:	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>
Aigun	54.8	9.7	18.5	0
Harbin	15.5	24.4	60.9	0
Vladivostok	4.0	1.5	9.0	0
Newchwang	5.4	102.3	357.1	0
Mukden	33.9	112.6	261.7	0
Tientsin	17.4	7.3	14.6	0
Taming				0
Chefoo	2.5	37.0	42.9	0
Tsingtau	77.7	95.3	50.4	0
Hwohklu	26.0	4.5	60.3	0.6
Chenkiang	135.9	30.2	7.4	6.6
Chengt'u				
Nanking	149.5	9.9	34.6	12.2
Wuhu	48.7	4.3	134.6	23.3
Iehang	8.9	55.1	18.8	0
Shanghai	42.8	14.3	30.5	57.2
Hankow	70.6	0	1.3	0
Ningpo	0	17.0	50.0	48.9
Kiukiang	107.5	138.0	77.2	24.1
Chungking	1.0	1.5	41.4	10.1
Wenchow	13.3	254.4	10.5	249.6
Chan'sha	29.2	0	1.0	1.3
Yunnanfu				
Poochow	7.6	80.2	0	60.5
Amoy	42.2	5.1	0	85.3
Swatow	180.8	6.8	0	322.4

TABLE 1.—*Rainfalls accompanying four typhoons of 1911—Contd.*

Stations.	June 28- July 8. No. 55.	July 12-21. No. 59.	Aug. 8- 15. No. 66.	Sept. 24- Oct. 11. No. 76.
CHINA—Continued.	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>
Wuchow.....	3.6	2.0	0	0
Lungechow.....	50.0	77.3	0	0
Nanning.....	186.0	172.6	0	0
Shanshu.....	37.8	0	0	10.9
Hongkong.....	85.0	0	0	109.4
Pakhoi.....	239.8	0	0	0
KOREA:				
Chemulpo.....	3.0	2.5	0	0
Jensan.....	35.0	22.0	6.5	0
Fusan.....	267.2	0	0	0
FORMOSA:				
Kelung.....	11.0	23.0	39.0	—
Taichiu.....	42.0	84.0	0	—
Tainan.....	5.0	170.0	0	—
Taitung.....	—	417.0	—	—
Hunchen.....	—	441.0	—	—
JAPAN:				
Kobe.....	—	0	—	—
Kyoto.....	—	1.0	—	—
Fuku.....	—	—	—	—
Tokio.....	—	3.0	—	—
Takuyama.....	—	47.0	—	—
Fukushima.....	—	28.0	—	—
Nagano.....	—	52.0	—	—
Akita.....	—	12.0	—	—
Hakodate.....	—	36.0	—	—
Sapporo.....	—	9.0	—	—

The Galveston hurricane of August 13-23, 1915.

In many ways this was one of the notable hurricanes in recent years. Although any single hurricane can not be taken as a representative of other hurricanes with regard to the rainfall distribution, it is nevertheless

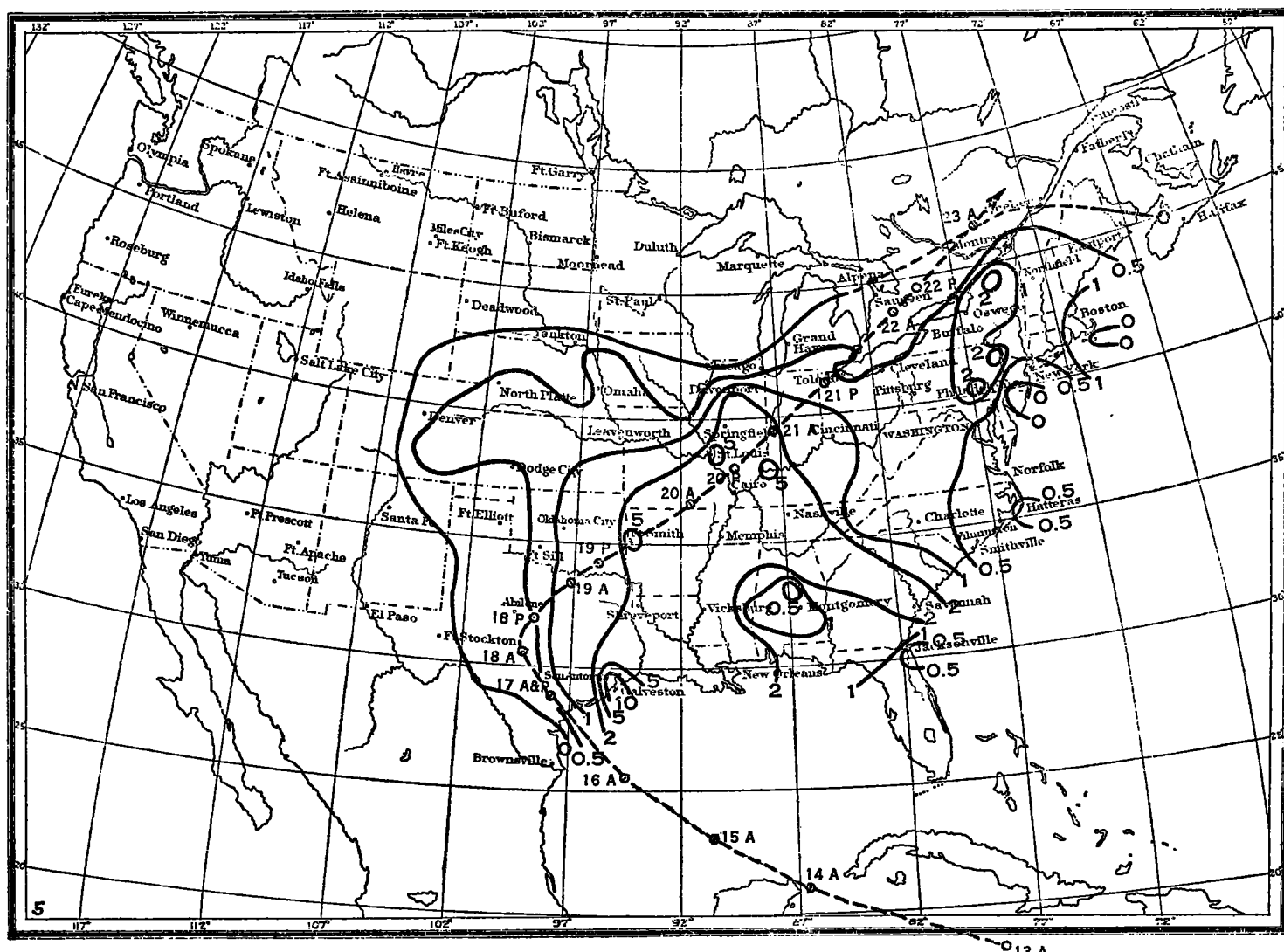


FIG 9.—Distribution of precipitation and the track of the Galveston hurricane of August 13-23, 1915. [The track has been corrected from unpublished data.]

interesting to compare the rainfall distribution map (fig. 9) of this storm with the maps of the four typhoons just discussed. Prof. A. J. Henry⁶ has pointed out in connection with this storm that the distribution of rainfall in a tropical storm is different from that in an extratropical storm. In the latter the rain is not distributed so uniformly about the center as in the former. This storm, he continued, maintained its tropical character until it reached the upper Ohio Valley. The heavy rainfall in Galveston and Houston should be noted (see Table 2), as these stations are on the coast where the storm passed from sea to land. In this connection it might be mentioned that during the New Orleans hurricane of September 29, 1915, New Orleans had a precipitation of about 209 mm. (8.26 inches) within 24 hours on September 29.

TABLE 2.—Amount of rainfall received during the Galveston hurricane of Aug. 13-23, 1915.

Place.	Amount.		Place.	Amount.	
	Inch.	Millim.		Inch.	Millim.
Galveston, Tex.	15.87	403.10	Staunton, Va.	0.74	18.80
Houston, Tex.	9.12	231.65	Buffalo, N. Y.	0.74	18.80
St. Louis, Mo.	8.18	207.77	Parkersburg, W. Va.	0.70	17.78
Evansville, Ind.	5.60	142.24	Kansas City, Kans.	0.70	17.78
Fort Smith, Ark.	5.98	151.89	Hartford, Conn.	0.68	17.27
Spring field, Ill.	4.60	116.84	Pueblo, Colo.	0.66	16.76
Memphis, Tenn.	4.91	124.46	Omaha, Nebr.	0.65	16.51
Shreveport, La.	4.82	122.43	North Platte, Nebr.	0.64	16.26
Nashville, Tenn.	4.54	115.32	Wytheville, Tenn.	0.68	17.27
New Orleans, La.	4.64	117.86	Montgomery, Ala.	0.66	16.76
Harrisburg, Pa.	4.38	111.25	Tampa, Fla.	0.62	15.75
Burwood, La.	3.88	98.55	Asheville, N. C.	0.62	15.75
Atlanta, Ga.	3.42	86.87	Lynchburg, Va.	0.61	15.49
Calro, Ill.	3.34	84.84	Cleveland, Ohio	0.64	16.26
Mobile, Ala.	3.34	84.84	Detroit, Mich.	0.60	15.24
Canton, N. Y.	3.30	83.82	Sioux City, Iowa.	0.56	14.22
Chattanooga, Tenn.	2.98	75.9	Charlotte, N. C.	0.54	13.72
Vicksburg, La.	2.79	70.87	Portland, Me.	0.52	13.21
Scranton, Pa.	2.18	55.37	Meridian, Miss.	0.51	12.95
Augusta, Ga.	2.56	65.02	Wilmington, N. C.	0.48	12.19
Savannah, Ga.	2.09	53.9	Chicago, Ill.	0.48	12.19
Peoria, Ill.	2.05	52.07	Erie, Pa.	0.45	11.43
Cincinnati, Ohio.	1.98	50.29	Toledo, Ohio.	0.44	11.18
Taylor, Tex.	1.97	50.04	Norfolk, Va.	0.44	11.18
Charleston, S. C.	1.93	49.02	Jacksonville, Fla.	0.41	10.41
Fort Worth, Tex.	1.92	48.77	Grand Rapids, Mich.	0.34	8.64
Columbia, S. C.	1.86	47.24	Richmond, Va.	0.32	8.13
Pensacola, Fla.	1.67	42.42	Cheyenne, Wyo.	0.26	6.60
Louisville, Ky.	1.66	42.16	Key West, Fla.	0.25	6.35
Syracuse, N. Y.	1.49	37.85	Abilene, Tex.	0.21	5.33
Indianapolis, Ind.	1.44	36.58	Birmingham, Ala.	0.20	5.08
Macon, Ga.	1.37	34.80	Lincoln, Nebr.	0.18	4.57
Boston, Mass.	1.32	33.53	Des Moines, Iowa.	0.18	4.57
Lexington, Ky.	1.22	31.99	New York, N. Y.	0.16	4.06
Oklahoma, Okla.	1.20	31.48	Del Rio, Tex.	0.11	2.79
Thomasville, Ga.	1.20	30.48	Raleigh, N. C.	0.09	1.52
Block Island, R. I.	1.10	27.94	New Haven, Conn.	0.05	1.27
Oswego, N. Y.	1.10	27.94	Nantucket, Mass.	0.05	1.27
Wichita, Kans.	1.08	27.43	Eastport, Me.	0.04	1.02
Palestine, Tex.	1.06	26.92	San Antonio, Tex.	0.03	0.76
Baltimore, Md.	0.97	24.64	Dodge City, Kans.	0.01	0.25
Albany, N. Y.	0.96	24.38	Venice, Colo.	0.01	0.25
Northfield, Vt.	0.96	24.38	Quebec, Ont. riv.	0.00	0.00
Columbus, Ohio.	0.93	23.62	Corpus Christi, Tex.	0.00	0.00
Hatteras, N. C.	0.92	23.37	Milwaukee, Wis.	0.00	0.00
Binghamton, N. Y.	0.92	23.37	Alpena, Mich.	0.00	0.00
Knoxville, Tenn.	0.88	22.35	Philadelphia, Pa.	0.00	0.00
Montreal, Quebec	0.88	22.35	Atlantic City, N. J.	0.00	0.00

Conclusions.

So far as these five tropical storms are concerned, we can say: (1) That the distribution of rainfall in tropical storms is uniform when compared with the extratropical storms; (2) that the heaviest rainfall usually occurs on that portion of the coast where the storm passes from sea to land; (3) that the velocity of these storms did not decrease as they passed from sea to land; and (4) that the heaviest precipitation usually occurs along the trajectory. In case, however, the storm goes far inland this rule does not hold. In this respect the behavior of the tropical storms resembles that of the extratropical storms. In the study of cyclonic distribution of rainfall in the United States, W. G. Reed⁷ found that the area of heaviest precipitation usually occurred on the side which was nearest a large source of moisture.

⁶ Henry, A. J., Rivers and floods for August, 1915. MONTHLY WEATHER REVIEW, August, 1915, 43: 413.

⁷ Reed, W. G. Study of the cyclonic distribution of rainfall in the United States. MONTHLY WEATHER REVIEW, Oct. 1911, 39: 1609-15. 11 figs.

RADIATION EQUILIBRIUM AND ATMOSPHERIC RADIATION.¹

By R. EMDEN.

(Abstract and translation by H. BATEMAN, Govans, Md., Aug. 14, 1916.)

1. INTRODUCTION.

Much attention is being paid in the United States to the study of atmospheric radiation and many valuable investigations have been carried out by American meteorologists. These workers have also shown a kindly interest in the researches of European scientists, and as a proof of this the Smithsonian Institution has recently published the admirable work of Anders Ångström in its Miscellaneous Collections (v. 65, no. 3, 1915). An important advance in the theory of atmospheric radiation was made about seven or eight years ago when W. J. Humphreys² and E. Gold³ showed that the sudden decrease of the vertical temperature gradient to a very low value, which is indicated when a balloon rises above the convective region, can be profitably studied in connection with the theory of radiation equilibrium. In Emden's paper the study of this relation is carried further, Humphreys's formula for the temperature of the isothermal region is obtained in another way and Gold's mathematical investigations are repeated and developed under slightly different assumptions. Some of the theoretical results closely resemble those obtained by Gold and are summarized with other interesting conclusions in the latter part of the paper which is printed here in full. The first part of the paper contains a critical survey of the work of Schwarzschild, Gold, and Humphreys and the theory is presented in a clear light. Schwarzschild's method is developed and applied to the case in which the radiation is composed of two parts, each of which can be treated as gray. Emden's work has been summarized by Schmauss in the Meteorologische Zeitschrift (1913, 48: 454). The same periodical also contains a further contribution to the mathematical analysis by Schwarzschild (Ibid., p. 454), and an article by Gold (Met. Ztschr., 1914, 49: 89), in which he expresses his views on some of the questions that have been raised with regard to the fundamental hypotheses. As some points are apparently still disputed,⁴ a brief résumé of Emden's argument may perhaps be of interest.⁵

2. FUNDAMENTAL ASSUMPTIONS.

(1) In radiation equilibrium each particle of air radiates out just as much energy as it receives from other particles and from external sources if there any. Thus radiation equilibrium obtains when the temperatures of the parts and consequently also the arrangement of the masses are not altered by radiation and absorption. The fundamental condition is that of the equality of the amounts of radiation given up and taken in, irrespective of its composition as regards wave length, state of polarization, and direction.

(2) To simplify the mathematical problem, pressure, density, and temperature are supposed to vary only with the altitude, and the curvature of the level surfaces is neglected. In radiation equilibrium each horizontal layer is supposed to radiate (according to its temperature) just as much energy as it receives from other layers and external sources. *The flow of energy in an upward direc-*

¹ Emden, Robert, in Sitzungsber., K. bayerische Akad. d. Wissensch., München, 1913, 43: 55-142.

² Astrophysical Journal (1909).

³ Proc. Roy. Soc. A. 82, 1919, p. 43.

⁴ Cf. Met. Zeitschr., May, 1914, 31: 239.

⁵ For more recent presentations of the theories of Gold and Humphreys see: E. Gold, The International Kite and Balloon Ascents, Geophysical Memoirs, No. 5 (1913). W. J. Humphreys, Journal of the Franklin Institute, March (1913).